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EDITORS AND PROPRIETORS,

JAMES D. DANA, B. SILLIMAN, AND E. S. DANA.

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ART. VII.—*On the production of Transparent Metallic Films by the Electrical Discharge in exhausted tubes; by* ARTHUR W. WRIGHT, Professor of Molecular Physics and Chemistry, Yale College.

THE spectra of gases contained in vacuum-tubes, which have been prepared by the use of the mercury pump, usually exhibit lines caused by the presence of the vapor of this metal. In some cases this is no disadvantage, since they serve as convenient reference points in fixing the position of the other lines or bands observed. As the mercury vapor is naturally an excellent conductor of electricity, however, there is often reason to suspect that its presence may affect the character of the discharge somewhat, and its removal becomes desirable. In some recent experiments by the writer this end was obtained by placing in each tube a few pieces of clean gold foil loosely rolled into small pellets. As this metal is readily amalgamated it will, after a time, take up the mercury vapor, causing the disappearance of its characteristic lines from the spectrum. A still better method is to wrap a small piece of the foil about the end of the electrode, or to attach to it a short gold wire. The gold will be volatilized and deposited upon the walls of the tube in a very thin layer, thus exposing a much larger surface to the action of the mercury vapor, in the manner described below.

In some of these experiments the tube under examination was so placed that the gold lay at the bottom of the upper portion, at the point where the capillary part is attached. In this position it was exposed to the action of the more intense discharge through the narrow part, and after a time it was found that a lustrous and coherent film was deposited upon the glass, the gold having evidently been volatilized by the electricity and condensed upon the walls of the tube. In order to study more conveniently the conditions under which the best effects might be produced, a loose roll of the foil was placed in the middle of a tube about five millimeters in caliber, having a branch near one end for the purpose of withdrawing the air, and with platinum electrodes inserted into the ends. This was exhausted until a discharge from an induction coil passed readily, when it was found that the gold was speedily deposited upon the tube as before, and by shaking the foil along, a considerable area was covered with it in a short time. It appeared, even under the microscope, as a perfectly continuous film, forming a brilliant mirror, and showing the characteristic green color by transmitted light very beautifully. When the tube was afterwards rather strongly heated the gold lost its mirror-like surface in the thinner parts, assuming a frosted appearance, and the light passed through it had a fine ruby color, conforming in this to what was observed by Faraday in his experiments on the relation of metals to light.* A singularity in the result was the fact that the volatilization occurred only at that end of the foil which was made a negative pole. This was observed to be the case in all the subsequent experiments, except that in one or two instances where a powerful discharge had been maintained for a considerable time a very slight deposit was observed at the positive end also.

As the matter appeared to be of interest with respect to its furnishing a new method of producing transparent metallic films, the investigation was extended to a considerable number of metals. Various forms of tubes were employed in successive trials, but the method found most advantageous was the following: clean tubes of white glass, about fifteen centimeters in length, and with a caliber of from four to six millimeters, were provided in the middle with a small branch tube for attachment to the pump. In the ends were placed the electrodes formed of the metals to be examined. These were generally in the form of thin wires from one-fourth to one-half a millimeter in thickness. About one centimeter of this was enclosed in a thin glass tube about three centimeters long, drawn out of the same piece as the main tube, and made so fine at the end as just to receive the wire. A platinum wire was placed in the other end, so as to touch the first wire, and sealed in. This was then carefully sealed into the end of the main tube, the electrode being in its axis, and the platinum wire projecting. It was necessary to cover the latter thus in the interior to prevent its giving a deposit upon the tube with the metal under examination. The tube was now exhausted to a tension of one or two millimeters, or so far that, when the discharge from the induction coil was passed through it, the glow surrounding the negative pole filled the tube along the whole extent of the electrode. After the coil had been put in operation for a few minutes a deposit was formed upon the glass, appearing at first as a mere darkening or discoloration, which, gradually becoming deeper, finally began to show metallic luster, while still suffering the light to pass freely. In almost all cases it covered the whole area of the glass opposite the electrode, but did not extend much beyond it. After the film was sufficiently developed the small branch was closed with a gas flame, the tube drawn off, and sealed.

* Experimental Researches in Chemistry and Physics.

For metals readily oxidized it was necessary to fill the tubes with some gas which would not act upon the deposit formed, as otherwise it was impossible to obtain good results. In these cases the air was first thoroughly removed, the tube filled with pure dry hydrogen, and then exhausted. In a few cases the tubes were refilled with hydrogen several times to ensure the complete removal of the oxygen. The perfection of the film was found to depend also in some measure upon the steadiness of the electrical action, and the proper regulation of the power of the current used. When the Holtz machine was employed as a source of electricity no effect was obtained without condensers, and with them the discharge, at least with the tension of gas used, did not occur in such a manner as to yield good results. The trifling deposit obtained in this way was opposite the positive electrode. Possibly by exhausting the tubes so as to reach a much lower tension the electro-machine might be made available, but the induction coil is both efficient and convenient.

With a gold wire one-third of a millimeter in diameter and four centimeters long, an exquisitely beautiful deposit was formed over a space a little longer than the wire. The first noticeable effect was a slight discoloration of the tube by the deposited metal, while it was still too thin to show the metallic luster by reflected light. The tint was pinkish, inclining to violet, resembling that at the more refrangible end of the spectrum. As the film increased, the tint passed through blue, bluish-green, and finally, when of sufficient thickness, it appeared a clear, brilliant green, slightly inclining to bluish-green. By reflected light the film has a splendid luster, and the full golden color. It thins out gradually at the extremities, and becomes imperceptible at a point five or six millimeters from the end of the wire, with the same gradation of tints as was observed in its formation. The metallic reflection fades out in a similar manner, but ceases before the coloration.

With silver wire of about the same dimensions, the coating upon the tube was scarcely less beautiful and perfect. The full luster was developed gradually, and the light transmitted by the completed film is a pure, deep blue. Copper gives a fine lustrous mirror, appearing dull green by transmitted light. It is volatilized with more difficulty than the preceding metals. Bismuth on the other hand is obtained in a thin film with extreme ease, a battery of three small Grove cells with a coil giving a half inch spark producing the desired result in two or three minutes. The film is very transparent, and has a color such as would be produced by mixing a clear blue with a pure gray or neutral tint. The metallic layer is remarkably uniform, and of great beauty, possessing a brilliant luster by reflected light.

Platinum is volatilized with comparative ease, especially in a narrow tube. Its deposition on the glass in this way is a familiar occurrence, as few of the common vacuum tubes which have been subjected to the action of the induction coil for a long time fail to show the effect. In a small tube the layer is very bright, and is easily made thick enough to be quite opaque. When sufficiently thin, it transmits light of a gray color, with a slight bluish tinge. Palladium also is deposited in a thin layer without difficulty, and appears of a smoky brown color by transmitted light. Lead forms a very even film, with the characteristic color of the metal, though it has but a comparatively feeble luster. It has a high degree of transparency, appearing of a smoky-brown color, inclining to an olive tint when very thin. Thorough exclusion of the oxygen and vapor of water is necessary to the successful formation and preservation of the film, as when exposed to the air or moisture it is destroyed by oxidation in a very few minutes.

Zinc and cadmium yielded brilliant mirrors, with a white, silvery luster, and appearing deep grayish-blue by transmitted light, with a barely noticeable inclination to purple. It is less deep in tint than the light passed through silver, but deeper than that from bismuth. There was no perceptible difference between the two metals, unless it were a slightly greater intensity of the coloration in the case of the zinc.

Aluminum was volatilized with considerable difficulty, requiring five or six cells and a powerful coil. It formed a mirror-like film, which by transmitted light had a brownish color, but the result was not entirely satisfactory. Magnesium yielded even less readily, and showed no effect at all when tried with the means which had given good results in the other cases. It was necessary to reduce the electrode to a very fine wire, and this was enclosed in a tube of only 3·5 millimeters caliber. The larger coil was used, and the power of the battery gradually increased to six Grove cells. Not the slightest effect was produced when a smaller number was employed, but after the application of this power for a few minutes, the electrode was suddenly surrounded by a burst of green light, and the deposit was formed almost instantly upon the glass. It had a brilliant luster, and when the light was seen through it, a grayish-blue color similar to that of zinc or cadmium, but less clear.

Tin did not give very satisfactory results, as when the electrode was made small enough for the purpose it was difficult to avoid fusing it. The film when obtained was not as fine as those produced with the other metals mentioned, but had in some parts a silvery metallic luster, and was sufficient to show that when seen by transmitted light the metal appears of a brownish gray or sepia tint.

Interesting results were obtained with iron, which gave a very beautiful and perfect film, having a brilliant luster, and a high degree of transparency. The light transmitted by it is very nearly of a pure neutral tint, though with a faint tinge of brownish. The electrode was a wire 0·3 millimeter in diameter. This was carefully cleaned, and the tube filled with dry hydrogen three times before the final exhaustion. Without this precaution it is impossible to obtain reliable results, as the metal is partially oxidized, and the film not only stained, but its color by transmitted light changed to brown, or even to deep orange-yellow. This was the color exhibited by the film obtained in the first trial, in which the tube was filled with air. Externally it exhibited a vivid iridescence, in various colors, but at the extremities of the deposit the metal had its proper luster. Subsequent trials in which the tube was once filled with hydrogen gave better results, but the yellow tint and the iridescence did not disappear until the thorough removal of the oxygen and moisture, as described.

For those metals which are not readily obtained in the form of thin wires, a modification of the process was employed, as follows: a tube open upon one side was made by softening the end of a glass tube in a gas flame and drawing out one edge with another piece of glass. A trough was thus formed, at first shallow but growing deeper and deeper as the whole edge began to be drawn upon, and by properly adjusting the heat applied, it could be made as fine as desired. A tube of this kind from half a millimeter to a millimeter in diameter with a platinum wire inserted in the closed end, and with the open end evenly and firmly packed with filings or powder of the substance to be examined formed the electrode, which was used in the ordinary way.

Nickel and cobalt were experimented upon by this method, and films obtained, but as the removal of the oxygen was not sufficiently complete they were less perfect than those produced from the other metals, though sufficient to show that the color by transmitted light is gray or brownish gray. Tellurium employed in the same way afforded a very brilliant layer, which gave to the light seen through it a dull purple color.

At the suggestion of Prof. Dana an experiment was made with magnetic oxide of iron, native magnetite in powder being employed with one of the small troughs. It was volatilized with difficulty, but apparently without decomposition, and formed a somewhat lustrous film, appearing gray-brown by transmitted light. The result is of interest with reference to the occurrence of thin, somewhat transparent layers of this substance in certain micas, where it has the same color as that observed in this experiment.

In Faraday's experiments deposits of several different metals upon plates of glass or other materials were obtained by passing the spark from a Leyden battery between the points of wires near the plates in an atmosphere of hydrogen. Films so obtained are more or less irregular, and he describes them as apparently not entirely continuous. Those formed by the method here described, however, are generally very uniform and coherent, and even under the microscope appear to be perfectly continuous. For a study of the optical properties of the metals they can be formed upon narrow slips of plane glass introduced into the tubes by the side of the electrode. Simple examination of the tubes with a Nicol's prism shows that these films, at least in the case of gold, silver, iron, zinc and cadmium, which have been tried by the writer, polarize the light transmitted by them powerfully, and the degree of polarization appears to increase with the incident angle as far as observation can be conveniently carried, which implies a very high refractive index. It might be expected that the light should be elliptically polarized, but this point was not determined, and the optical properties of the films remain for further study.

With respect to the relative energy of electrical action necessary to volatilize the different metals the observations were hardly precise enough to warrant the statement of a definite law. Bismuth was volatilized most readily of all, gold and silver with but slightly less facility. Platinum, palladium, lead, tin, zinc and cadmium yield less readily, while copper, iron, nickel and cobalt require a rather intense discharge and are volatilized with some difficulty. Aluminum requires an energetic electrical action exerted for a long time, and the electrode must be a quite fine wire. Magnesium is acted upon still less readily, and is by far the most difficult, of all the metals tried, to be obtained in the state of a thin layer. Success was attained by the use of an energetic battery of five or six Grove cells, with a coil capable of giving two-inch sparks, the electrode being a wire cut from a thin ribbon of the metal and not more than one-fifth of a millimeter in thickness. Even then no effect was produced till this was enclosed in a very narrow tube by which the electrical action was concentrated. The electrode itself appeared bright green, showing that the discharge did act upon the metal, forming a thin envelope of vapor about it, which did not reach the glass however until the power of the current was increased and the size of the tube considerably diminished. It will be seen that the heavy metals, that is, those with high atomic weights, are most readily volatilized, while those with smaller atomic weights oppose great resistance to the electrical action, and those with medium weights occupy an intermediate position; but the fusibility, tenacity, and electrical conductivity also appear to exert some influence as to the place of the different metals in the list.

It may be observed also that where it is desirable to avoid discoloration of vacuum-tubes by the metallic deposit, this can be effected by making the electrode within the tube of aluminum or magnesium, the interior portion of the platinum wire which passes through the glass being itself covered with a small glass tube. Of the two metals magnesium is the best, as a wire half a millimeter in diameter would not be at all affected by discharges of the intensity ordinarily used with vacuum-tubes, nor would it be so easily fused or rendered red hot as a wire of platinum. Of course these metals could only be used with gases which would have no chemical action upon them.

Yale College, December 13, 1876.

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## SCIENTIFIC INTELLIGENCE.

### I. Chemistry and Physics.

1. *On the so-called Crystallized Boron.*—Hampe has prepared and submitted to careful examination both of the forms of the so-called crystallized boron, the black and the yellow, and finds that neither is pure boron, both being compounds of this substance. For the preparation of the black variety, 200 to 400 grams of fused coarsely pulverized boric acid was placed in an English clay crucible, a piece of aluminum weighing 100 to 200 grams was laid upon it and covered with boric acid, and then the cover of the crucible was luted on with clay. The whole was enclosed in a Hessian crucible, the space between the two being filled with quartz sand. The secret of the production of the black crystals consists in the absence of carbon in the crucible. The fusion was effected in a melting furnace, the fuel used being coke, and the time of heating three hours. By closing the draft almost completely, the cooling took place very slowly, requiring from 12 to 18 hours; the crystals being increased in size proportionally. On breaking the inner crucible when cold, the upper layer of the fused mass was glassy and consisted of aluminum borate. Within this was a thin dense very hard layer of pure alumina, which surrounded the regulus. The free surface of the metal as well as the cavities in it were covered with magnificent black crystals, which were obtained on solution of the aluminum, accompanied by red hexagonal plates of the aluminum boride of Wöhler and chocolate-brown crystals of silicon. The yield was small, only 2·5 to 3 grams being obtained from 100 grams aluminum, one gram of which proved completely pure. Various other methods of preparation were tried; but the yield was less in every case. The crystals are monoclinic prisms, have a brilliant metallic luster,

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ART. XXII.—*On a new Process for the Electrical Deposition of Metals, and for constructing Metal-covered Glass Specula;* by Professor ARTHUR W. WRIGHT, Yale College.

IN a paper by the writer, published in this Journal, January, 1877, an account was given of a method of producing metallic films upon the inner surface of exhausted glass tubes, by the action of a succession of energetic electrical discharges. The thickness of these films could be varied, from a tenuity such that the coating barely gave indications of a metallic luster, and scarcely dimmed the intensity of transmitted light, to the point where perfect opacity was attained, by simply continuing the action of the current for a shorter or longer time. They were produced by forming the negative electrode of the metal to be deposited, exhausting the tube, and passing through it the current from an induction coil. The metallic coatings thus obtained, as seen from the exterior, were very brilliant, but the condition of the inner surface was not readily observed, and the nature of the process made it seem probable that they possessed a dull or even a frosted surface. With a view to obtain the films in a form better suited for examination, a modification of the apparatus was contrived, by which they could be deposited upon pieces of plane glass. At first this object was attained by inserting narrow slips of glass into the tube by the side of the electrode, in the manner suggested in my former paper, and very good results were gained. But, as the nearer portion of the plate received a larger share of the metal, the thickness of the deposit was not uniform, and it was found necessary to construct a special apparatus, in which the relative positions of the plate and the electrode could be varied, so as to give the latter an equal action upon all parts of the surface to be covered. The plan employed was as described in the following paragraphs.

A rather thick-walled glass globe about seven centimeters in diameter, blown upon the end of a tube twenty-five centimeters long and fifteen millimeters in diameter, was used to form the receiver. The top of the globe opposite the tube was cut off, so as to form an opening forty millimeters in diameter, and the edge ground flat, in a plane perpendicular to the axis of the tube. The end of the latter was drawn somewhat smaller in a gas-flame, and a glass stop-cock attached to it with cement. A little way above this, a platinum wire was fused into the glass to serve as the positive electrode. The cover of the vessel was made by cutting from a similar globe a portion corresponding in size to the part removed, but with the neck attached, the two pieces being carefully ground so as to fit closely. When they were placed together, a little cement applied to the outside along the line of juncture rendered the joint perfectly air-tight. The tube or neck of the cover was five centimeters long, and was also somewhat reduced at the extremity by drawing it smaller. Into this was cemented a small and thick-walled tube extending to a point near the center of the globe. A platinum wire was placed in this tube, and was fused in at the top, enough being left projecting to form a small loop for the attachment of the wire from the coil. The inner end of the wire terminated at about one centimeter from the lower end of the glass tube. Into the latter was slipped a wire of the metal to be deposited, which, in all cases, was the negative electrode,—the part within the tube being long enough to make good contact with the platinum wire, and being bent somewhat so as to cause it to retain its place by friction. In some of the experiments a different cover was used, made from a glass funnel, the neck of which was left somewhat longer to afford more room for the swinging electrode, as described below, and the tube carrying the latter was fitted into the top by grinding so as to make an air-tight joint.

For the support of the plate, a small watch-glass, about three centimeters in diameter, was employed, to one edge of which a thread of glass was fused by a blow-pipe flame, and then bent so as to form a loop by which it could be suspended like the pan of a balance. A small hook of glass was also attached to the side of the thick tube carrying the electrode, and upon this the pan was hung, the loop being so formed as to allow it to swing freely in all directions. The pan, when in place, was about fifteen millimeters below the end of the tube from which the electrode projected, the latter being adjusted to the proper distance by sliding it up or down in its support as occasion required. By slightly inclining the globe the extremity of the wire could thus be readily brought over any point of the plate. In some of the experiments the plate was stationary, being held in a little tripod of glass threads, or simply laid upon the bottom of the globe. In these cases the tube holding the electrode was jointed near the top, the two portions being connected by a hook and loop of platinum or magnesium wire. It could thus be made to traverse all parts of the plate by giving suitable movements to the globe.

When adjusted and closed the receiver was attached to the Sprengel pump. By means of a small air-pump of the ordinary construction, connected with this by a stop-cock and flexible tube, the whole apparatus was exhausted as far as possible and then dry hydrogen admitted, this being repeated two or three times in order to remove the air and moisture. The process of exhaustion was then completed with the mercury pump. The degree of rarefaction required varied somewhat with the metal to be deposited, but was rarely above 2·5 millimeters. For platinum the best results were obtained, when it was from 1·5 to 1·75 millimeters. The use of hydrogen is not in all cases necessary, as some of the metals can be deposited perfectly well with only air in the receiver. This is especially the case with gold, but platinum, although ordinarily not easily combined with oxygen, becomes tarnished with a film of what apparently is the blue oxide, unless the air is removed. The electrode itself was formed of a small wire, usually not more than one-fourth of a millimeter in thickness, bent at the end into a circle three or four millimeters in diameter, the plane of which was perpendicular to the straight portion of the wire entering the glass tube, and parallel with the surface of the glass plate situated beneath it. Its distance from the latter was generally about three millimeters, though considerable variations were possible. When it is farther away the process of deposition goes on much more slowly, though the results are in most cases quite as good as when it is nearer. After the process of exhaustion was completed, the stopcock was closed, and the apparatus removed from the pump, for greater convenience of manipulation in applying the current.

The electrical apparatus employed consisted of an induction-coil capable of giving sparks four or five centimeters in length, and a battery, the power of which could be varied according to circumstances. It consisted usually of pint Grove cells, from three to six in number, not completely filled, or charged with rather weak acid, and a plunge battery of five cells, of which one, two, or more were used, as occasion required, the whole being joined in a continuous circuit. By immersing the plates of the plunge battery more or less, as well as by varying the number in the circuit, the strength of the current could readily be changed within the limits desired. The various metals required currents of different strength, and the power best suited to each had to be determined by trial. It was found advisable in most cases to regulate it so that the temperature of the electrode was below that of a red heat, or such as barely to redden it. Of course with the more fusible metals it was necessarily much lower than this. The metal is actually volatilized by the discharge, as is shown by the fact that the characteristic lines of its spectrum may be seen with a spectroscope, and the film is formed by the condensation of its vapor upon the cooler glass surface. For the production of films with brilliant surfaces, the strength of the current must not be great enough to give the discharge a disruptive character, as this separates some of the metal in the form of powder.

The primary object of the experiments was to obtain films of the different metals upon thin pieces of flat glass for the purpose of investigating some of their optical characters. The apparatus proved to be perfectly successful in its operation, and beautiful films of gold, silver, platinum, and bismuth, were obtained with ease and certainty. As has been mentioned, it seemed probable that the surface of deposit would be dull, but the first trial showed that this anticipation was incorrect, and the films when removed from the receiver exhibited surfaces of exquisite perfection and the most brilliant polish. They can only be compared to the surface of clean liquid mercury, far surpassing in luster anything that can be obtained by the ordinary methods of polishing.

This circumstance suggested at once a valuable application of the process in the production of specula for optical purposes, and the subsequent investigations were directed to this end. The mirrors first made had been formed upon disks of thin glass, such as are commonly used as covers for microscopical objects, those being selected which were most free from defects, and had the best surfaces. By means of a very delicate assay balance, the weight of the glass disks, both before and after receiving the deposit, could be obtained to the one hundredth part of a milligram, and hence it was easy to calculate the thickness of the metallic layer in any instance. By this means the relative transparency of the different metals can be determined, and the relation between the amount of light transmitted and the thickness of metal traversed by it. The more particular consideration of these and some other matters of interest as bearing upon the optical characteristics of the metals is deferred to another time, and it is only necessary to mention here the results of some measurements which were made in order to determine the limiting thickness of a film in regard to the transmission of light, that is, the thickness of a film which would allow only an inconsiderable proportion of the incident rays to pass through. As the metallic luster is developed gradually with the increasing amount of metal, showing conclusively that light actually penetrates these substances to a certain depth, it was important to ascertain whether the thickness of the layer, sufficient for a virtually complete reflection of light, would be great enough to affect perceptibly the figure of a mirror of glass upon which it was laid down.

Experiments for this purpose were made with gold and platinum, and the process of deposition was continued until the films appeared to have just reached the condition of complete opacity. On removing them from the receiver, however, it was found in both cases that a very small amount of light was still transmitted, as, on holding them close to the eye, a brilliant object, like the sun or a bright flame, could be seen through them. The thickness of the gold layer was found to be 0·000183 mm., that of the platinum 0·000174 mm., or approximately one-fourth the length of a wave of light at the red end of the spectrum. The gold, although thicker than the platinum, transmits perceptibly more light, showing that it is the more transparent of the two metals. As the films employed for mirrors may be much thinner than the amount mentioned without an appreciable diminution of the intensity of reflected light, it is evident that the figure of a perfectly wrought glass mirror will not be changed, when the metal is uniformly deposited, to such an extent as to affect its performance unfavorably. A platinum film of one-fifth the thickness of the one described forms a brilliant mirror, transmitting but a very small percentage of light. The perfect control of the process obtained by the use of the movable electrode will even make it possible to apply the method of local correction for the improvement of a defective figure, or to parabolize a spherical mirror by depositing the metal in a layer increasing in thickness toward the center, though, of course, it would be better to avoid a somewhat tedious operation by securing the perfect form of the glass beforehand.

Of the metals that are suitable for the formation of specula, platinum appears to be the most valuable. For while, when well polished, it is but little inferior to silver in reflecting power and freedom from color, it does not become tarnished by oxidation or the action of sulphurous gases, and when dulled by atmospheric deposits the surface can be cleaned by washing with water or with acids, which is an important advantage. By the method here described it can be deposited upon glass surfaces very easily, and a mirror of the most perfect surface produced at once, without the necessity of a single touch to complete it. Several such mirrors have been made in the course of these experiments, by the use of concave glass lenses, with the most satisfactory results. The metal film adheres strongly to the glass, and when of sufficient thickness appears to be very firm and hard. In mirrors silvered by the ordinary method, trouble is often experienced from the insinuation of moisture between the glass and the metal, resulting finally in the separation of the latter. In those prepared by the new process the adherence of the film is so close as to render such an effect impossible. As a test of this, a small silvered speculum was placed in a beaker of water where it remained for two weeks, and besides this was wetted and dried repeatedly, without showing the slightest tendency to suffer the penetration of the moisture. Similar results were also obtained with platinum and gold films.

With silver the process likewise succeeds well, but it is more difficult to obtain good surfaces than with gold or platinum. The metal is volatilized with extreme ease by the action of the current, and the energy of the discharges must not be too great. Of several trials made with this metal the most successful was one in which not only the degree of exhaustion of the receiver was less than had been employed in other cases, being only to three millimeters, but the electrode was more distant from the plate, and the battery weaker. The action proceeded slowly in this instance, but with the result of producing an excellent film. With a stronger current the deposit is rapidly made, and has a fine luster, but the surface has a yellowish color. This is perhaps partially due to a slight degree of oxidation, but also appears to be owing in part to the deposition of a portion of the metal in the form of fine powder, the vapor of the silver as it streams from the electrode toward the more distant portions of the plate becoming partially condensed, and falling on it in minute particles. That such a result would follow from this cause was shown by some of the experiments in which a rather strong battery was employed. The whole interior surface of the globe was in a short time covered with the powdered metal, appearing an intense purple where thinnest, and shading gradually to deep blue where thickest, the color being the same by both transmitted and reflected light. The metallic luster was wanting, though it was readily developed when a portion of the powdery coating, which was easily removed, was rubbed against the surface of the glass with some pressure. The defect was, to a considerable extent, remedied by surrounding the electrode with a small glass tube projecting some three millimeters beyond it, so as to clear the surface of the plate by an interval of only one or two millimeters. This had the effect to cut off the lateral portion of the discharge, and to confine its action to a limited area immediately below the extremity of the wire.

The yellow tarnish is removed with the greatest ease by gently rubbing the surface with soft chamois leather and a little rouge, and the metal is so hard, that, when this operation is performed with care, the polish is not at all, or but very slightly, affected. Even then, however, the metal is not perfectly white, having still a very faint yellow tinge. It is well known that silver is not a perfectly white metal, for light which has undergone repeated reflections from polished surfaces of this metal appears yellow or reddish-yellow, though this color is not perceptible when the light has undergone but a single reflection. But the real cause of the yellowish tint may possibly be found in the very tenuity of the films, which when prepared in this way have a beautiful and intense blue color by transmitted light. When not too thick, the amount of blue rays which they suffer to pass, may be sufficient to cause, by their abstraction, a perceptible tinge of yellow, the complimentary color, in the reflected rays. If this were really the case, the coloration should grow weaker with an increase of thickness, and disappear when opacity is reached. Some of the results obtained seem to favor this view, and the probability of its correctness is strengthened by the facts related in the next paragraph, but further experiments are needed to decide the question satisfactorily.

One result of the investigation has been to show that the color of the light which has passed through a layer of metal varies somewhat with the thickness of the film. This was known to be the case with gold, and experiment has shown it to be true of platinum and bismuth also. Thus the latter in a very thin film appears a clear bluish-gray, while a much thicker film appears brownish. Platinum in a thin layer has a grayish tint, which varies, as the film is made thicker, to a peculiar brownish shade, somewhat like that of sepia, passing into brownish yellow, and finally becoming a deep yellow, even inclining somewhat to orange, in the thickest films obtained. Now this color is almost exactly complimentary to that transmitted by silver, and the possibility suggested itself of making a mirror which should be perfectly white by reflected light, by depositing first a thin stratum of silver and over this another of platinum, the relative thickness of the two being properly regulated by observing the color of the transmitted light. An experiment made with a circular disk of flat glass was perfectly successful, the platinum being readily deposited upon the silver, the yellowish tint of which it entirely removed, producing a white and brilliant reflecting surface. By transmitted light the film, as it was anticipated would be the case, has a pure neutral tint, with no perceptible color of any kind.

The value of such a combination for specula is evident; for though until careful measurements are made, it cannot be asserted that the absolute reflecting power is increased, the whiteness of the layer, and the protection afforded by having the surface covered with an unalterable metal, are very substantial advantages. In constructing large mirrors it will probably also be found to result in a material saving of time, the silver being so much more rapidly and easily deposited than the platinum. The process can also be used with great advantage for the construction of solar eye-pieces for telescopes, since the compound film can be deposited directly upon the surface of the lens, and made thick enough to reduce the intensity of the light as much as may be desired. An image, nearly or quite colorless could thus be obtained, and the disturbance of the rays should be less than that produced by the interposition of a dark glass of the ordinary kind.

As has been mentioned, some experiments were made with bismuth, and a mirror of excellent surface was obtained, but the metal is inferior to platinum in brilliancy, and has a decided color. The great facility with which films are obtained with it might recommend its use for mirrors in some cases, but for most purposes other metals are to be preferred. Attempts to produce mirrors of iron and nickel were but partially successful, as it was difficult to prevent tarnishing by oxidation. Some good iron films were obtained, however, which were very brilliant. They were exceedingly hard, and adhered to the glass with such tenacity that at first it seemed as if they had been fused into it. But when the film was dissolved off by an acid the glass was found not to have been acted upon at all. A singular characteristic of the iron in this condition is its chemical inertness. Films prepared more than six months ago and freely exposed to the air, which for a part of the time too, was excessively charged with moisture, have not shown the least alteration. Nitric acid placed upon one of them for a short time produced scarcely any effect, and nitro-hydrochloric acid acted upon it with about the same readiness as it does upon platinum. This may be due to the extreme thinness of the film, in consequence of which, even the exterior atoms of the iron, being within the range of the molecular action of the glass, are held by a force tending to oppose and neutralize the attraction of reagents that ordinarily attack the metal energetically.

It is not at all necessary that the object upon which the metal is deposited should be of non-conducting material. This is shown by the fact that the process continues to go on after